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Possible Transiting Planet Candidates from the EXPLORE Project

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Abstract.
The EXPLORE Project is a series of searches for transiting extrasolar planets using large-format mosaic CCD cameras on 4-m class telescopes. Radial velocity follow-up is done on transiting planet candidates with 8–10m class telescopes. We present a summary of transit candidates from the EXPLORE Project for which we have radial velocity data.

1. Introduction

The EXPLORE (EXtrasolar PLanet Occultation REsearch) Project is a series of searches for transiting extrasolar planets orbiting Galactic plane stars using 4-m class telescopes. As an integral part of the search strategy, radial velocity (RV) follow-up observations for mass confirmation are done on 8–10m class telescopes. In June 2001, we used the CTIO 4-m telescope for 11 nights (6 clear) to observe the EXPLORE I field, located at $l = -28, b = -3$ (Mallén-Ornelas et al. 2002). The best 37,000 light curves were examined, and RV follow-up of three planet candidates was done on the VLT in September 2001 (Mallén-Ornelas et al., in prep.). In December 2001 we used the 3.6-m CFHT for 16 nights (14 clear) to observe the EXPLORE II field, located at $l = 203, b = 0.7$ (Yee et al., in prep.). The best 12,000 light curves were examined, and RV follow-up of 2 planet candidates and 2 additional eclipsing systems was done at Keck in February 2002 (Mallén-Ornelas et al., in prep.). Here we present a summary of the transiting planet candidates for which we have RV follow-up.

2. What Makes a Good Transiting Planet Candidate?

Light curves with very precise photometry and good time sampling can be used to determine the eclipse shape and select the best transiting planet candidates with minimal contamination from other systems that can mimic the transit signature. In general terms, the best planet candidates will have very shallow eclipses ($\lesssim$2–3%, implying a small companion) of short duration ($\lesssim$3h for a 3–4 day period transit, implying a dwarf star), with a clear flat bottom, and preferrably with a steep ingress/egress (i.e., a "box shape"). For a full discussion on candidate selection and possible contaminants see Seager & Mallén-Ornelas (2002) and Mallén-Ornelas et al. (2002). A mass measurement from RV observations is required in order to confirm the presence of a planet, as opposed to a brown dwarf or a stellar companion. In particular, the RV data should show only one velocity peak (indicative of the presence of a single star), and ideally result in a mass detection (with $M_{planet} < 13 M_J$). Note that in the absence of an actual mass detection, a good upper limit of 1–2 M_J may be used to make the case for a planet *as long as the eclipses can be confirmed with certainty, and possible contaminants can be ruled out with confidence.*

3. Possible Planet Candidates from the EXPLORE Project

A total of three planet candidates from the EXPLORE I search were followed-up with the VLT+UVES in September 2001. For the EXPLORE II search, two planet candidates as well as two (brigher) stars with deeper eclipses were observed with Keck+HIRES in February 2002. Based on the window function of our observations, on the number of light curves examined, assuming that 0.75% of single stars have a close-in giant planet, and adopting a binary fraction of 1/2, we expect to find 1 planet in the EXPLORE I search and 1–2 planets in the EXPLORE II search. Here we summarize our preliminary findings on the five planet candidates for which we have conducted RV follow-up observations. The essential information is presented in tables 1 and 2, and a brief discussion is given for each candidate. A full description of our results will be presented in two future papers (Mallén-Ornelas et al., in prep.). Light curves and preliminary RV plots for some of the systems discussed here can be found in Yee et al. (2002).

3.1. Summary of Possible Planet Candidates

Table 1 lists the I and V magnitudes, eclipse depth, and period for the five transiting planet candidates with RV follow-up. Note that in some cases it is possible that the period listed is a multiple of the true period, since additional intervening eclipses may have occurred during the day. Table 2 gives the eclipse and RV characteristics of the transit candidates, which can be used to determine whether each system is a good planet candidate. *As mentioned in § 2, the best planet candidates have "box-shaped" short-duration eclipses with clear flat bottoms. In the case of a planet the RV should show only one velocity peak in the cross-correlation, and any RV variations should be of very small amplitude.* For some of the EXPLORE data, poor S/N in the light curve prevented us from ascertaining the eclipse shape in some cases, marked with a "?" in Table 2. Bad weather during the RV follow-up resulted in poor phase coverage for EX2c11s4809, which unfortunately prevented us from measuring a mass for this otherwise promising planet candidate.

Table 1: General characteristics for transit candidates with RV follow-up

Star ID	I (mag)	V (mag)	# of Eclipses	Eclipse Depth (mag)	Period (days)
EXP1c02s46830	16.1	17.7	1[1]	0.015	?
EXP1c01s52805	16.2	17.9	2	0.03	2.2
EXP1c07s18161	17.6	19.4	2	0.025	3.8
EXP2c11s4809	18.3	20.0	3	0.017	3.0
EXP2c10s5069	18.4	20.1	4	0.008	4.0

[1] there is a possible second low-S/N eclipse in this object

Table 2: Eclipse and RV characteristics for transit candidates with RV follow-up

Star ID	Eclipse Characteristics			RV Characteristics		Possible
	Flat?	Boxy?	Short?	Peaks	Shifts	Planet?
EXP1c02s46830	?	N	Y	1	Y	?
EXP1c01s52805	Y	N	Y	2	Y	No
EXP1c07s18161	?	?	Y	1	N	Yes
EXP2c11s4809	Y	Y	Y	1	?	Yes
EXP2c10s5069	?	?	Y	1	N	Yes

3.2. Individual systems

• **EXP1c02s46830.** Only one clear eclipse was detected, and the long ingress and egress duration make it an unlikely planet candidate. A steady decrease in RV of $\sim$500 m/s was detected over the 8 days spanned by the observations. However, a planet cannot be ruled out until a period is measured (either from the eclipses or the RV variations) which will enable a mass determination.

• **EX1c01s52805.** The RV data for this object had two velocity peaks, revealing a system composed of a close eclipsing binary, plus a brighter superimposed star with no significant RV shifts. Note that the eclipses for this system have clear flat bottoms but *are not* "box-shaped". Although it is possible for a planet crossing close to the stellar limb to produce transits with a long ingress and egress, such planet transits are much less common than "box-shaped" transits (Seager & Mallén-Ornelas 2002).

• **EXP1c07s18161.** This system has 2 detected eclipses, though the S/N is not high enough to ascertain eclipse shape with confidence. There is only one RV peak, and we place a preliminary upper mass limit of 2–3 M_J. Thus, this is a very promising planet candidate. To definitely establish this system as a planet, we require further photometric observations to confirm the eclipses, and ideally more RV data to obtain an actual mass detection.

• **EXP2c11s4809.** This system has very clear flat-bottomed eclipses, and only one RV peak. However, due to poor weather we were unable to obtain enough phase coverage to place a useful mass limit. Further RV observations leading to a mass measurement are required to establish the nature of this system.

• **EXP2c10s5069.** We detected 4 eclipses, but all with very low S/N so the eclipse shape could not be determined with certainty. Only one RV peak was found, with no detected shifts. To establish this system as a planet we need more RV data to attempt a mass detection, as well as photometric observations to increase the S/N of the eclipses.

4. Summary and Conclusions

We have presented a status report on the transit candidates from the EXPLORE Project's first two surveys. Out of three systems with RV follow-up in the EXPLORE I search, one was found to be a close stellar binary plus a blended star, a second one is an unlikely planet candidate that nonetheless has not been entirely ruled out as a planet, and a third one is a promising planet candidate based on an upper mass limit. The two candidates with RV follow-up in the EXPLORE II search remain good planet candidates, although more RV data are required for both systems, and more photometric data are also desirable for EXP2c10s5069, which has extremely shallow eclipses detected with low S/N.

We have shown that it is possible to produce a clean set of planet candidates from a deep transit search and place meaningful mass limits (2–3 M_J) on the companions via follow-up RV observations. We emphasize that in order to find one good planet candidate, it is necessary to monitor several thousands of stars with good time coverage, high photometric precision, and time sampling which is good enough to determine the eclipse shape.

References

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